Defense Technical Information Center Compilation Part Notice

ADP010615

TITLE: Navigation in a Virtual Environment Using a Walking Interface

DISTRIBUTION: Approved for public release, distribution unlimited

This paper is part of the following report:

TITLE: The Capability of Virtual Reality to Meet Military Requirements [la Capacite de la rea1ite virtuelle a repondre aux besoins militaires]

To order the complete compilation report, use: ADA388966

The component part is provided here to allow users access to individually authored sections of proceedings, annals, symposia, ect. However, the component should be considered within the context of the overall compilation report and not as a stand-alone technical report.

The following component part numbers comprise the compilation report:
ADP010609 thru ADP010633

NAVIGATION IN A VIRTUAL ENVIRONMENT USING A WALKING INTERFACE

Stuart C. Grant and Lochlan E. Magee
Defence and Civil Institute of Environmental Medicine
1133 Sheppard Ave.
North York, Ontario M3M 3B9, Canada

For years, aircraft crews and armored fighting vehicle crews have benefited from training in the benign, controlled, and instrumented situations created by simulation. Virtual reality (VR) technologies are now starting to bring these benefits to the training of dismounted soldiers.

Simulation for dismounted combatants has numerous applications. In current combined arms simulations, only constructive infantry, controlled from a workstation, are available. Their lack of sophistication, relative to their human counterparts, is thought to detract from the validity of the combined arms simulation. Adding virtual infantry would increase the benefit to all participants. Reconnaissance forces and special operations units could plan and rehearse missions using simulation. The ability to explore a future area of operations, such as an airport where hostages are being held, from a first person perspective would allow forces to assess and rehearse lines of fire, escape routes, and fields of view. Similarly, personnel who must enter toxic environments, such as ship's damage control parties and nuclear power station maintenance crews could rehearse different scenarios ahead of time and familiarize themselves with locations they have never visited.

A HUMAN FACTORS PROBLEM: NAVIGATION

A human factors problem threatens to prevent dismounted combatants from obtaining the full benefits of simulation. People are prone to becoming lost in virtual environments (VEs) (Durlach & Mavor, 1995; Psotka, 1995). This is obviously a problem, for being lost impairs performance in the virtual environment and it means that there is little spatial knowledge being gained for transfer to the real world.

Conventional movement interfaces for VR, such as joysticks and 3D mice, likely contribute to disorientation because they do not provide the vestibular and kinesthetic feedback people use to navigate in the real world (Loomis, Da Silva, Fujita, & Fukusima, 1993; Mittelstaedt & Glasauer, 1991; Schmuckler, 1995). Thus, only visual information is available for navigation by dead reckoning (Gallistel, 1990), and that source of information is constrained by the limited vection produced by the narrow fields of view obtained in most VR displays. Seeking to address this problem, Iwata and Matsuda (1992) provided users with special roller skates to move through a VE. The effect of their interface on users' distance perception in a VE relative to a point-and-fly interface was equivocal, however. Slater, Usoh, and Steed (1995) used the presence of foot motion to move users in a VE and found positive effects on feelings of immersion, but they did not measure navigation effects.

AN EXPERIMENT

This experiment examined the role of proprioception in the navigation of VEs by letting subjects explore a computer model of a large, complex building, the Ontario Science Centre (OSC), using either a walking interface or a joystick. If proprioception facilitates navigation in VEs, subjects using the walking interface should be better oriented in the VE and acquire more knowledge of the OSC for transfer to the real world. To aid the interpretation of the results, the experiment included control groups that either studied a map of the OSC, walked through the real OSC, or received no information about the OSC.

The VE

The OSC is an excellent place to study navigation because it has an unconventional floor plan and contains many unusual items, thus providing unique and memorable locations while preventing subjects from finding their way using heuristics derived from their experience with more common buildings. For this experiment a model of 7,200 square meters of the

Paper presented at the RTO HFM Workshop on "The Capability of Virtual Reality to Meet Military Requirements", held in Orlando, USA, 5-9 December 1997, and published in RTO MP-54.

OSC, including hundreds of exhibits, was constructed using shaded polygons. Eight of the exhibits were selected as destinations for the navigation task according to their location in the OSC, their size, and their distinctive appearance.

The Walking Interface

The walking interface was a platform 1.22 m in diameter surrounded by a hand rail. The surface of the platform was covered with a slippery laminate that allowed subjects to easily slide their feet across the surface.

Subjects wore a magnetic sensor on each foot. By walking in place, the subject's foot motion moved the subject's eye point in the VE. Horizontal foot movement, either forward or backward along the subject's body direction produced forward movement in the VE. This is similar to normal walking, where the head moves steadily forward as the feet move back and forth beneath the body. The farther and faster the subject moved his feet on the platform, the farther and faster he moved in the VE. On the basis of a pilot experiment, the magnitude of the foot movement was amplified to produce a subjective match between walking speed and visual flow.

Design of the experiment

Eighty subjects, all older than 15, completed the experiment. The nature of recruiting resulted in a different ratio of men to women in each experimental condition, but because inclusion of gender as a covariate in the analyses reported below did not change any of the results, the effects of gender will not be reported.

Five groups of 16 subjects took part in the experiment. The VR-walking group explored the computer model of the OSC using the walking interface. The joystick group did the same using a joystick. The map group explored the OSC using a floor plan that contained representations of all exhibits, and by looking at photographs of the destination exhibits. The real-walking group explored the real OSC. The no-experience group received no information about the spatial arrangement of the OSC, but they did see photographs of the destination exhibits.

In the first phase of the experiment, subjects in the VR-walking, joystick, and map groups completed a simulator sickness assessment. The assessment consisted of a 28 item questionnaire (the Simulator Sickness Questionnaire, the SSQ; see Kennedy, Lane, Berbaum, & Lilienthal, 1993) and an eyes-open Romberg balance test, performed on a force platform.

In the training phase, the experimenter guided all subjects, except the no-experience subjects, through one circuit of the OSC, visiting the eight destinations. The VR-walking and joystick groups did this by moving through the computer model. The map group was directed along a path on the map, viewing photographs of each destination as they reached it on their map. The real-walking group followed the tour in the real OSC, and the no experience group only viewed the photographs of the destinations. At the start of the tour the experimenter told the subjects that they would be asked to find the destinations later in the experiment, and that they should attempt to learn the location of the destinations.

To determine how well the subjects were oriented in the VE, each time the VR-walking and joystick groups reached a destination during the training phase, they were asked to face back to the origin of their VR tour. If they were disoriented, they should make large errors, but if they were not, their errors should be small. To provide a performance benchmark, the real-walking subjects performed this same task while walking in the real OSC.
Upon completing the training phase the VR subjects and the map subjects again completed the simulator sickness test.

In the transfer phase, the subjects attempted to find the shortest path to the eight destinations in the real OSC. The experimenter named a destination and the subject sought only that destination until it was found. The subjects were asked to find the destinations in an order that differed from the order in which they saw them in the training phase. This was done to force the subjects to find new routes and truly navigate rather than just recall the path followed during training. The time and distance taken to find the destinations were recorded.

Results

In the orientation task, the mean absolute angular error from the attempts to point back to the origin of the tour (± 1.96 standard error of the mean) were 33° (±14°), 71° (±14°), and 66° (±8°) degrees for the walking, VR-walking, and joystick groups, respectively. An ANOVA showed that there was a difference amongst the groups, $F(2,39) = 13.11$, $p <$

.01. Planned comparisons indicated that the two VR groups performed worse than the real-walking group $F(1,39) = 26.21$, $p <.01$, but they did not differ from each other, $F(1,39) < 1$.

The mean distances required by each group to find the destinations are presented in Table 1. There are significant differences amongst the means, $F(4,75) = 5.71$, $p < .01$. In particular, the VR-walking group followed a shorter path than the joystick group, $F(1, 75) = 3.99$, $p < .05$. The VR-walking group was also superior to the no-experience group, $F(1,75) = 7.16$, $p < .01$, but the joystick group was not, $F(1,75) < 1$. The route taken by the joystick group was farther than that taken by the real-walking group, $F(1,75) = 12.94$, $p < .01$, but the difference between the VR-walking group and the real-walking group was not significant, $F(1, 75) = 2.83$, $.10 > p > .05$. Similarly, the map condition did not differ significantly from the joystick group, $F(1, 75) = 1.42$, $p > .10$, or the VR-walking group, $F(1, 75) <1$.

	Real Walking	VR-walking	Joystick	Map	No Experience
Mean Distance (m)	643	753	886	805	928
Mean Time (s)	599	805	938	909	969

Table 1. Performance in the Transfer Phase

The mean times to find the destinations are reported for each group in Table 1. Following a square root transformation of the time data to alleviate heterogeneity of variance, an ANOVA revealed differences amongst groups, $F(4,75) = 5.91$, $p < .01$. Planned comparisons indicated that the VR-walking group required less time than the no-experience group, $F(1,75) = 3.15$, $p < .05$, but the joystick group did not, $F(1,75) <1$. Both the VR-walking and joystick groups took more time than the real-walking group, $F(1,75) = 6.77$, $p < .05$ and $F(1,75) = 14.71$, $p < .01$, respectively. The differences between the map group and each VR group were not significant, both $F(1, 75) <1$. Finally, the VR-walking group did not differ from the joystick group, $F(1, 75) = 1.78$, $p > .10$.

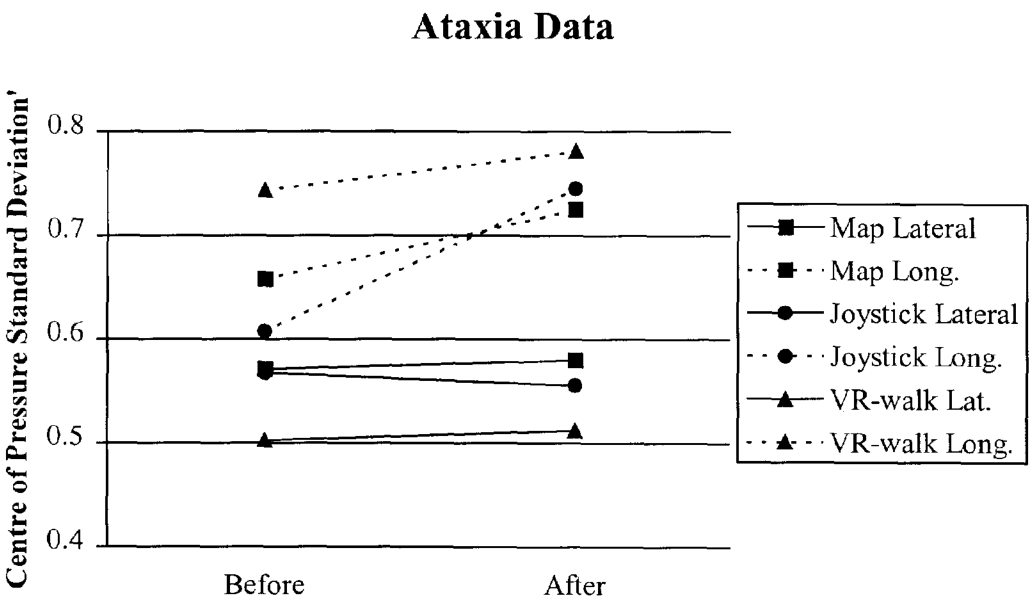

Figure 1.

The data from the balance test, presented in Figure 1, revealed no effect of the VR training. The changes in lateral and longitudinal instability experienced by the VR groups were no greater than those experienced by the map group, all $p > .1$.

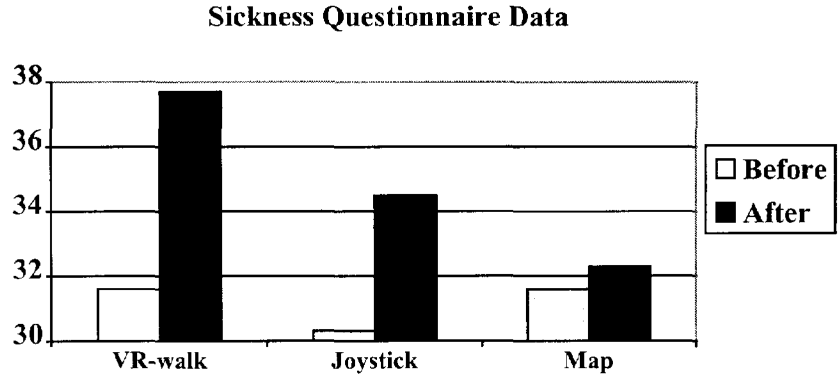

Figure 2.

The sickness questionnaire data in Figure 2 show that the increase in symptoms following training was significantly greater for the VR groups than the map group. Using conversion equations provided by Knerr (1997), SSQ scores were derived from the **questionnaire** data and are presented in Figure 3

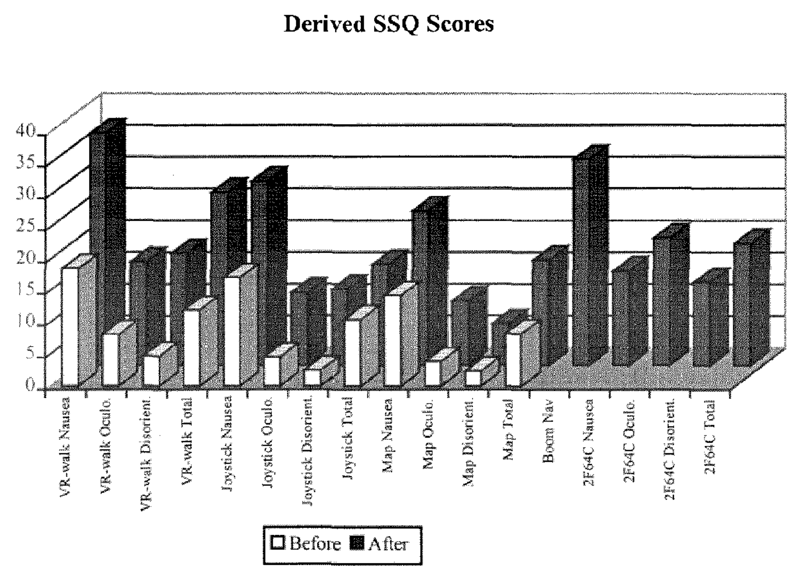

Figure 3.

along with scores from another VR system, (Witmer, Bailey, & Knerr, 1996) and the worst of 10 surveyed flight simulators (Kennedy, Lane, Berbaum, & Lilienthal, 1993).

CONCLUSIONS

This experiment documented that people can become quite disoriented in VEs and that the best way to learn about a space is to visit that space. However, VR proved itself to be an effective alternative to training in the real location. Spatial knowledge acquired in a VE can assist performance in the real world, but success is not assured. Navigation in VEs remains a human factors problem.

A walking interface to VR is helpful. It does not appear to help subjects remain oriented in the VE, but people transfer more knowledge to the real world if they use the walking interface rather than a joystick (at least in terms of finding the shortest path to a destination).

The VR system used here caused simulator sickness, but the levels were not severe. They were comparable to other VR systems and some flight simulators. In terms of SSQ scores, this system seems to appear particularly nauseagenic, but there is reason to argue against this conclusion. This experiment was conducted during the winter, when many subjects were carrying thick coats. This may have caused higher responses to the sweating item in the nausea scale. Indeed, of the items used to derive the nausea score, the sweating item had the highest mean.

Walking interfaces to VR appear to have significant military value. Users demonstrate better navigation performance if they use a walking interface rather than a joystick. This is important, not just for its own sake, but also because it indicates that users may be able to obtain non-visual information for navigation using the walking interface. Thus, they might be able to navigate when visual information is scarce due to smoke, night, lack of data for construction of a visual database, or when landmarks are destroyed. Furthermore, not being dependent on landmarks for navigation allows for improvising new routes out of sight of known landmarks.

The walking interfaces available for obtaining these benefits can be compared on four dimensions pending further results on the role of proprioception in navigation. Ideally the interface will be inexpensive, simple, unobtrusive, and allow the user to physically turn in any direction. A conventional treadmill has several advantages. It is inexpensive, simple, and permits a normal gait, free from wires. However, it only supports movement in one direction. The omni-directional treadmill allows walking in any direction with a normal gait, free from wires, but it is expensive and complex. The rollerskate system developed by Iwata and Matsuda (1992) is simple, affordable, and allows movement in any direction, but it encumbers the user with wires and a harness. Slater, et al. (1995) developed a simple and inexpensive omni-directional interface, but it uses wired sensors that simply moves the subject at a pre-set speed. The feedback from walking naturally is not available. For this experiment a walking interface was developed that was low-cost, simple, and omnidirectional, but it does not allow a completely natural gait, and the user must wear wired sensors on each foot.

Ultimately, a better understanding of human navigation is required to field an optimal walking interface. The kinesthetic and the vestibular systems are both involved, but their relative contributions are not known. Also unknown is the type of information derived from each system. Both can sense angular and linear movement. Once the nature of the information is known, and how important it is, new hardware can be targeted to provide only the information necessary, freeing the user from the costs and constraints entailed in providing the unnecessary information.

REFERENCES

Durlach, N.I., & Mavor, A.S. (1995). *Virtual Reality: Scientific and Technological Challenges.* Washington DC: National Academy Press.

Gallistel, C.R. (1990). *The Organization of Learning.* Cambridge, MA: MIT Press.

Iwata, H. & Matsuda, K. (1992). *Haptic walkthrough simulator. International Conference on Artificial Reality and Tele-Existence.*

Kennedy, R.S., Lane, N.E., Berbaum, K.S., & Lilienthal, M.G. (1993). A simulator sickness questionnaire (SSQ): A new method for quantifying simulator sickness. *International Journal of Aviation Psychology, 3*, 203-220.

Knerr, B. (1997). Personal communication.

Loomis, J.M., Da Silva, J.A., Fujita, N., & Fukusima, S.S. (1993). Visual space perception and visually directed action. *Journal of Experimental Psychology: Human Perception and Performance, 18*, 906-921.

Psotka, J. (1995). Immersive training systems: Virtual reality and education and training. *Instructional Science, 23*, 405-431.

Mittelstaedt, M. & Glasauer, S. (1991). Idiothetic navigation in gerbils and humans. *Zool. Jb. Physiol. 95*, 427-435.

Schmuckler, M. A. (1995). Self-knowledge of body position: Integration of perceptual and action system information. In P. Rochat (Ed.) *The Self in Infancy: Theory and Research.* North-Holland: Elsevier Science.

Slater, M., Usoh, M., & Steed, A. (1995). Taking Steps: The influence of a walking technique on presence in virtual reality. *ACM Transactions on Computer-Human Interaction, 2*, 201-219.

Witmer, B.G., Bailey, J.H., & Knerr, B.W. (1996). Virtual spaces and real world places: Transfer of route knowledge. *International Journal of Human-Computer Studies, 45*, 413-428.